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# Search for Anomalous Production of Photon, $b$-jet, and Missing Transverse Energy at CDF

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We report the results on two signature-based searches for new physics using 1.9–2.0 fb$^{-1}$ of data collected at the CDF experiment. Both analyses look in events containing a photon, a $b$-tagged jet, and missing transverse energy. The first search requires an additional jet. The second search requires an extra electron or muon. No significant excess of events over the Standard Model prediction is observed. We also describe the "CES/CPR" method which is used to estimate the amount of mis-identified photons.



## 1. SEARCH FOR ANOMALOUS PRODUCTION OF $\gamma bj\not\!\!E_T$

The CDF collaboration has performed a signature-based search in the inclusive $\gamma bj\not\!\!E_T$ final state using 2.0 fb$^{-1}$ of data. The $\gamma bj\not\!\!E_T$ signature raised great interest for two main reasons. First, this final state has been predicted by several SUSY models[1][2, 3], *e.g.*, the production of a chargino and a neutralino, when $\tilde{\chi}_2^0$ is photino-like and the LSP $\tilde{\chi}_1^0$ is Higgsino-like, via the decay chain: $\tilde{\chi}_1^+\tilde{\chi}_2^0 \rightarrow (\bar{b}\tilde{t})(\gamma\tilde{\chi}_1^0) \rightarrow (\bar{b}c\tilde{\chi}_1^0)(\gamma\tilde{\chi}_1^0) \rightarrow (\gamma\bar{b}c\not\!\!E_T)$. Second, the dominant backgrounds are mis-identifications of either the photon or the $b$-quark candidates and mismeasurements of the jet energy which induce $\not\!\!E_T$ not associated with unobserved neutral particles (fake $\not\!\!E_T$). The SM processes which produce real $\gamma bj\not\!\!E_T$ are expected to contribute at most 2%. Therefore, a significant excess in data will be an indication of new physics. Events are required to have a central[2] photon with transverse energy $E_T > 25$ GeV, at least two jets with $E_T > 15$ GeV and $\left|\eta^{\rm det}\right| < 2.0$, at least one of the jets must be identified as originating from a $b$ quark ("$b$-tagged") using the tight SECVTX algorithm [4], and missing transverse energy $\not\!\!E_T > 25$ GeV. Figure 1 shows the $\not\!\!E_T$ and dijet mass $M_{bj}$ distributions from data and predicted background. Other kinematic distributions, such as jet multiplicity, $E_T$ of photon, $E_T$ of $b$-tagged jet, *etc.*, have also been examined and no significant excess has been found. The observed number of events in data is 617, which is consistent with the expected number of background events, $637 \pm 139$.

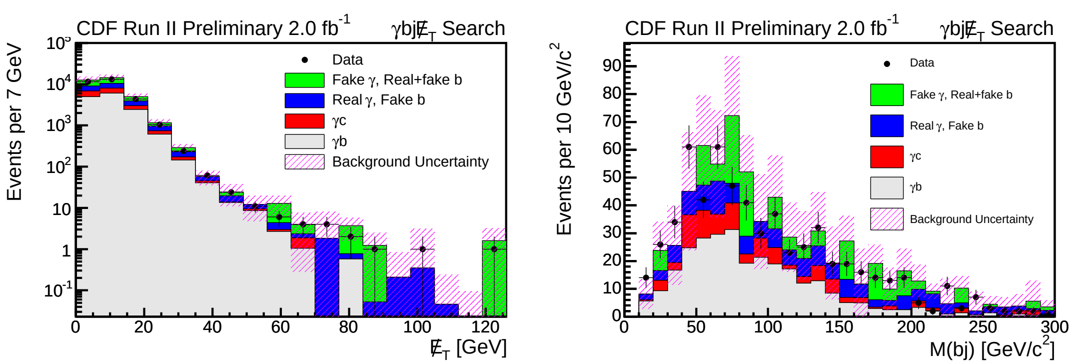


Figure 1: CDF search for anomalous production of $\gamma bj\not\!\!E_T$: the $\not\!\!E_T$ (left) and $M_{bj}$ (right) distributions observed (markers) and background prediction (filled histograms). The hatched-region indicates the total uncertainty on the predicted background in each bin.

[1]These models had been proposed to explain the CDF $ee\gamma\gamma\not\!\!E_T$ event observed in Run I [1].
[2]Throughout this document, all central objects have detector pseudo-rapidity $\left|\eta^{\rm det}\right| < 1.1$.

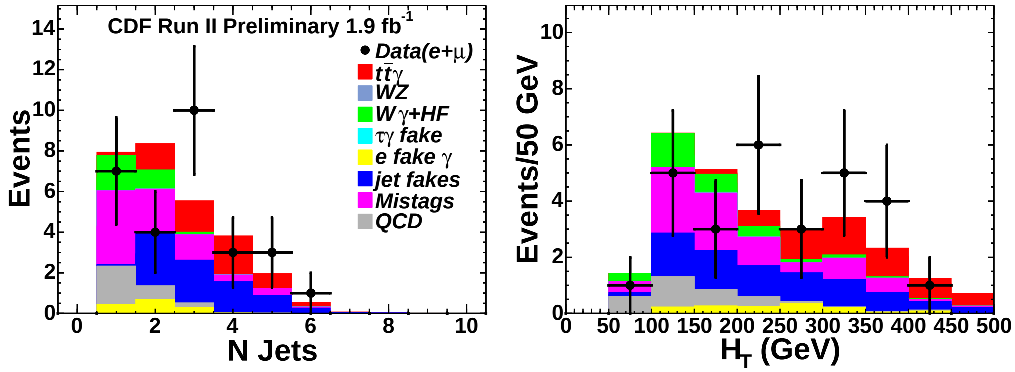


Figure 2: CDF search for anomalous production of $\ell\gamma b\not\!\!E_T$: the jet multiplicity (left) and $H_T$ (right) distributions observed (markers) and background prediction (filled histograms). The contribution of SM $t\bar{t}\gamma$ increases as the jet multiplicity and $H_T$ increase.

## 2. SEARCH FOR ANOMALOUS PRODUCTION OF $\ell\gamma b\not\!\!E_T$ and Measurement of SM $t\bar{t}\gamma$ Production Cross-section

Ref. [2] predicts in the Minimal Supersymmetric Standard Model (MSSM) an exotic decay channel of the top quark, which may compete with $t \to Wb$, into a light stop and a light Higgsino-like neutralino. A $t\bar{t}$ pair may then decay via $t\bar{t} \to Wb\tilde{t}\tilde{\chi}_i \to \ell\bar{\nu}_\ell bc\tilde{\chi}_1^0\tilde{\chi}_1^0\gamma + X$. Instead of searching for this MSSM model only, the CDF collaboration has performed a model-independent search in the inclusive $\ell\gamma b\not\!\!E_T$ final state using 1.9 fb$^{-1}$ of data, where $\ell$ is an electron or a muon. Since this signature is rare, the $E_T$ and $b$-tagging requirements are looser than those in Section 1: a central electron or muon with $p_T > 20$ GeV, a central photon with $E_T > 10$ GeV, at least one jet which is $b$-tagged by the loose SECVTX algorithm [4], and $\not\!\!E_T > 20$ GeV. Figure 2 shows the jet multiplicity and $H_T$[3] distributions from the inclusive $\ell\gamma b\not\!\!E_T$ final state. No significant excess in data is found: 28 observed and $27.9^{+3.6}_{-3.5}$ expected. The background has a significant contribution from the SM $t\bar{t}\gamma$ production, especially in the lepton + jets channel. After requiring $H_T > 200$ GeV and two additional jets ($\geq 3$ jets with $\geq 1$ $b$-tag in total), the $t\bar{t}\gamma$ cross-section has been measured to be $0.15 \pm 0.08$ pb, which is consistent with the next-to-leading-order (NLO) prediction, $0.080 \pm 0.012$ pb [5].

## 3. ESTIMATION OF MIS-IDENTIFIED PHOTONS

The number of events with mis-identified photons is estimated by the "*CES/CPR method*" [6], where we use cluster-shape variables from the central electromagnetic strip and wire chamber system (CES) [7] and hit rates in the central preshower detector (CPR) [8]. The primary misidentified photons come from $\pi^0 \to \gamma\gamma$ or $\eta^0 \to \gamma\gamma$ decays where the hadrons are associated with jets. For photon candidates with $E_T < 35$ GeV, the shape of the shower profile measured with CES can be used to discriminate between true single photon events and diphoton final states from decays of mesons. We construct a $\chi^2$ by comparing the measured shower profile with that from electron test beam data. A single photon has an average probability of $\sim 80\%$ to satisfy a $\chi^2$ cut, while the background has an average probability of $\sim 30\%$, since the shower profile of the two near-by photons from a meson decay is measurably wider on average. Above 35 GeV, however, the two photons from $\pi^0$ decay coalesce and the discrimination power of the shower profile measurement is lost. In this $E_T$ range, we use hit rates in the CPR system to discriminate between single photons and diphotons from meson decays. A single photon will convert and leave a hit in the preshower detector

[3] The $H_T$ is defined as the scalar sum $p_T$ of all identified objects, including $\not\!\!E_T$, in an event.

with a probability of $\sim 65\%$. Backgrounds that decay into two photons have a hit probability of $\sim 85\%$ because the probability that neither photon converts is lower than the probability that a single photon does not convert. The difference of probabilities between signal and background forms the basis of a statistical method which assigns each event a weight for being a mis-identified photon. The weight is a function of the energy of the photon candidate, the angle of incidence, the number of primary interactions found in the event, the shower profile $\chi^2$, and whether or not the photon candidate leaves a hit in the preshower detector. The number of background photons, $N_{\mathrm{bkg}}$, is a sum of these weights:

$$N_{\mathrm{bkg}} = \sum_i W_i = \sum_i \frac{\epsilon^i_{\mathrm{sig}} - \epsilon^i}{\epsilon^i_{\mathrm{sig}} - \epsilon^i_{\mathrm{bkg}}}, \tag{1}$$

where $\epsilon^i$ is one or zero depending on if photon candidate $i$ satisfies the CES/CPR requirement or not[4]. The $\epsilon^i_{\mathrm{sig}}$ and $\epsilon^i_{\mathrm{bkg}}$ are signal and background efficiencies given the kinematic information of photon candidate $i$ and are parameterized using subsidiary measurements. The "CES/CPR" method has been used in the measurement of inclusive photon and diphoton cross-sections and the search described in Section 1. It may be applied in the measurement of $\gamma b\bar{b}$ cross-section and other searches in the future.

## 4. CONCLUSION

The CDF collaboration has performed signature-based searches in the $\gamma b \not\!\!E_T + X$ final state, where $X$ is an additional jet, an electron or a muon. We have not yet found significant excess in 1.9–2.0 fb$^{-1}$ of data. We have measured the Standard Model $t\bar{t}\gamma$ cross-section to be $0.15 \pm 0.08$ pb. The current measurement has a large statistical uncertainty and may be improved as more data data are being collected. Finally, we briefly describe the "CES/CPR" method which is used to estimate the contribution of mis-identified photons. This method may also be used in the future measurements of cross-sections and searches for new physics.

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[4]CES shower profile $\chi^2 < 4$ for $E_T < 35$ GeV and CPR ADC counts above threshold for $E_T \geq 35$ GeV.